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**APPLICATION
FOR
UNITED STATES
LETTERS PATENT**

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FOR: **CIRCUIT AND METHOD FOR
EXCHANGING SIGNALS BETWEEN
NETWORK NODES**

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TITLE OF THE INVENTION

"CIRCUIT AND METHOD FOR EXCHANGING SIGNALS BETWEEN
NETWORK NODES"

BACKGROUND OF THE INVENTIONField of the Invention

The present invention relates to transmission and reception of signals between devices (nodes) attached to a computer over a serial bus such as the IEEE-1394 bus specified according to the IEEE-1394 Standard for a High Performance Serial Bus (or IEEE Std 1394-1995).

Description of the Related Art

The IEEE 1394 standard specifies protocols for the transmission and reception of various control signals and communication signals between peripheral devices of a computer such as printers, hard disk drives, scanners, digital cameras (nodes) at different layers of each node connected to a serial bus. For the physical layer of each node, a procedure is specified for bus initialisation and determination of bus ownership. This procedure is described by a state machine having four broadly classified functions. The bus initialisation procedure consists of three network initialisation processes (Bus Reset process, Tree ID process, and Self ID process) and a Normal process (for normal communication between nodes).

For each of these processes a number of states are defined. For Bus Reset process, states R0 (Reset Start) and R1 (Reset Wait) are defined, and for Tree ID process states T0 (Tree ID start), T1 (Child Handshake), T2 (Parent Handshake) and T3 (Root Contention) are defined. Similarly, five states are defined for Self ID process, including S0 (Self ID Start), S1 (Self ID Grant), S2

1 (Self ID Receive), S3 (Send Speed Capabilities) and S4 (Self ID Transmit), and
2 six states are defined for Normal process, including A0 (Idle), A1 (Request),
3 A2 (Grant), TX (Transmit), RX (Receive) and PH (PHY Response). The
4 present invention is concerned with Tree ID and Normal processes. The
5 sequences of line states that occur during a Tree ID process and a Normal
6 process are respectively shown in Figs. 1 and 2.

7 In Fig. 1, a Tree ID process between nodes A and B is shown. This
8 process is a handshaking process which begins with the node B asserting a
9 Parent Notify state on the serial bus. Node A, on detecting the Parent Notify
10 state, asserts a child notify state on the serial bus. In response, the node B
11 deasserts the parent notify state and returns the bus to Idle state. With this
12 process, the node A is determined as a parent of node B and the node B as a
13 child of node A.

14 Fig. 2 shows the essential states of a state machine of a node during
15 Normal process which are concerned with the present invention. The node
16 has each connected port labelled parent if it is pointing towards the root node
17 that is authorised to assign the ownership of the serial bus and labelled child
18 if it is pointing towards a node (i.e., child) located on one side of the node that
19 is opposite to the root node. State A0 indicates the Idle state of the node in
20 which it drives an idle signal to the serial bus. If a node, except for the root
21 node, is in the Idle state and receives a Request signal from its child port, it
22 changes to state A1. If the root node receives a Request signal from its child
23 port, it changes from Idle state to state A2 (= Grant). If a node, regardless of
24 its type, receives a Data Prefix (i.e., indicating the start of transmission of
25 data) during state A0, it changes to state RX in which it receives packets.

1 If the node is in state A1 and receives a Grant signal from its parent
2 port, it changes to state A0 (= Idle) if a Request signal from its child port is
3 cancelled or changes to state A2 (= Grant) if such a Request signal persists. If
4 the node receives a Data Prefix from the parent port, it recognises that a
5 Request signal from its child port is cancelled and changes to state RX in
6 order to receive packets from the parent port. If a node is in state A1 (=
7 Request) to transmit packets and receives a Grant signal from the parent
8 port, it changes to state TX in order to transmit packets.

9 When the node is in state A2 (= Grant), it changes to state A0 if it
10 receives a Request cancel signal from its child port, or changes to state RX if it
11 receives a Data Prefix signal. If the node is in state RX, it changes to state A0
12 if it receives an Idle signal from the port from which packets are being
13 received. If the node is in state TX, it returns to state A0 at the end of
14 transmission of packets.

15 Fig. 3 shows various line states of nodes A and B interconnected by
16 shielded twisted pairs TPA and TPB (with a maximum length of 4.5 meters)
17 when they exchange arbitration signals to gain bus ownership using data-
18 strobe encoding. The twisted pairs are reversed at the midpoint of the cable
19 so that the TPA and TPB viewed from node A are the TPB and TPA viewed
20 from node B. During initial state, node A is signalling an Idle state by driving
21 an Idle signal to both TPA and TPB, which is indicated as a line state (TPA,
22 TPB) = (Z, Z).

23 Table 1 indicates a contention state in which the Request signal (Z, 0)
24 from node A and the Idle signal (Z, Z) occur simultaneously on the cable and
25 the line state of the cable as viewed from node B changes to a differential

1 state (0, Z). Recognising that the node A has transmitted a Request signal, the
2 node B responds to it with a Grant signal to give the bus ownership to node A.

3 Table 2 indicates another contention state in which node A sends a
4 Request signal (Z, 0) while node B sends a Grant signal (Z, 0). The line state of
5 the cable viewed from node A changes to a differential state (0, 0). Node A
6 recognises that the ownership of the bus is granted and transmits a Data
7 Prefix signal (0, 1) that precedes subsequent packets.

8 Table 3 indicates another contention state in which node A asserts a
9 Data Prefix signal (0, 1) and node B asserts a Grant signal (Z, 0). Node B
10 interprets the resulting differential line state (1, 0) as a Data Prefix signal and
11 deasserts the Grant signal in order to receive packets from node A. In Table 4,
12 node 1 asserts a Data Prefix signal (0, 1) and node B is in Idle state (Z, Z).
13 Node 1 sees the differential line state (0, 1). Since this line state is the same as
14 one that node A has sent, the node A does not respond to it. In this way,
15 nodes attached to an IEEE-1394 serial bus exchanges information in a half-
16 duplex mode.

17 Consider a three-node network of Figs. 4A to 4D in which a node 2 is
18 shown as the root node authorised to grant bus ownership. If nodes 1 and 3
19 assert Request signals R1 and R2 on child ports "0" and "2" of root node 2 as
20 shown Fig. 4A and root node 2 receives R1 earlier than R2, the root node
21 grants bus ownership to node 1 by asserting a Grant signal G3 on the child
22 port "0" and informs node 2 of the fact that its request is denied by asserting
23 a Data Prefix signal D3 on the child port "2" as shown in Fig. 4B. Node 1
24 sends a Data Prefix signal D4 which is followed by a packet P5 (Fig. 4C). Root
25 node 2, on receiving the packet P5, successively transmits a Data Prefix D6 to

1 node 3 before sending the packet P5 as a packet P7 (Fig. 4D). If the distance
2 between nodes 2 and 3 are relatively short, it is likely that node 3 has
3 deasserted the Request signal R2 before the packet P7 arrives, and hence no
4 contention arises between R2 and P7.

5 In more detail, when the node 1 asserts the Request signal R1, the root
6 node 2 responds with the Grant signal G3 (Fig. 5A). On receiving the Grant
7 signal G3, the node 1 deasserts the Request signal R1 and transmits Data
8 Prefix D4. Root node 2 then deasserts the Grant signal G3 to enter a packet
9 receiving mode. Note that the length of the Grant signal G3 from root node 2
10 is equal to the turnaround time between nodes 1 and 2. The length of Data
11 Prefix D4 is greater than the turnaround time to prevent contention between
12 packet P5 and Grant signal G3. When the node 3 asserts the Request signal
13 R2, the root node 2 is asserting the Data Prefix D3 (Fig. 5B). On receiving the
14 Data Prefix D3, the node 3 deasserts the Request signal R2. In order for a
15 packet from the root node 2 to be transmitted without encountering Request
16 signal R2, it is necessary that the length of Data Prefix D3 is greater than the
17 turnaround time between nodes 2 and 3. If these nodes are spaced apart a
18 distance of 4.5 meters, the turnaround time is approximately 50 nanoseconds.
19 Since the minimum length of the Data Prefix is specified as 140 nanoseconds,
20 no contention occurs between the packet from root node 2 and Request signal
21 R2 from node 3.

22 Development efforts for longer bus-length transmission have recently
23 culminated as the P1394b Draft Standard for a High Performance Serial Bus
24 (Supplement Draft 0.17 April 23, 1999). The draft standard provides protocol
25 for serial transmission of data on a full-duplex mode between nodes attached

1 to an optical fiber or unshielded twisted pairs (UTP) to ensure full-duplex
2 communication over a length longer than 4.5 meters, using 8B/10B block
3 codes. The newly developed protocol may be used in combination with the
4 current protocol of data-strobe codes. As one example, a four-node network
5 is shown in Fig. 6, in which the distance between nodes 3 and 4 is greater than
6 4.5 meters and hence they are interconnected by 8B/10B ports, each including
7 (as shown in Fig. 7) an 8B/10B encoder 11 and a parallel-to-serial converter
8 12 and a serial-to-parallel converter 13 and an 8B/10B decoder 14.

9 However, there is a likelihood of a situation in which a Request signal
10 would remain asserted (i.e., not cancelled) in the longer-than-4.5-meter bus
11 section and contend with other signals. As shown in Fig. 8A, assume that
12 node 1 successively transmits a Data Prefix signal and a packet after it has
13 acquired bus ownership and node 4 sends a Request to node 3 to request the
14 bus ownership. The Data Prefix and the packet from node 1 are retransmitted
15 by root node 2 to node 3, where they are further retransmitted to node 4.
16 When the node 4 receives the Data Prefix signal from node 3, it deasserts the
17 Request signal (Fig. 8B). However, if the data length of the packet from node
18 3 to node 4 is shorter than the distance between nodes 3 and 4, the node 3 will
19 receive, after it has retransmitted the packet to node 4, the Request signal
20 which remains asserted as a "ghost" between nodes 3 and 4. This ghost
21 Request signal is received by node 3 and retransmitted to root node 2. Root
22 node 2 responds to this ghost Request with a Grant signal as shown in Fig. 8C,
23 and the node 4 responds to the packet from node 1 with an acknowledgment
24 packet. After transmitting a Request signal, the node 3 enters a standby mode
25 waiting for a Grant signal from its parent port. Since the node 3 is in the

Transitions of state machines of nodes 3 and 4 during a Normal process are shown in detail in Fig. 9. When a Data Prefix (DP) signal from node 2 arrives on node 3, the node 3 is in state RX, while the node 4 is in state A1 asserting a Request signal. Node 3 then retransmits the DP message and the following packet (PKT) and Date End (DE) message to node 4 and then momentarily changes to state A0 (= idle). Since the 8B/10B port of node 3 is still receiving the Request signal from node 4 after it has retransmitted the DE message to node 4, the node 3 changes to state A1 (= Request) following a momentary change to state A0. On the other hand, the node 4 receives the retransmitted Data Prefix signal (DP) from node 3 and deasserts the Request signal and changes to state RX to enter a packet receive mode for receiving DP, PKT and DE. Since the node 3 is in state A1 (= Request) at the instant the Request signal from node 4 is terminated, the Request signal remains as a ghost and propagated from node 3 to root node 2. Meanwhile, the node 4 receives the DE message from node 3 and changes to state TX to send a DP signal and an acknowledgment (ACK) message and a DE message to node 3. Node 3 is in state A1, waiting for a Grant signal from its parent port. If the ACK message arrives on node 3 in state A1, the state machine of node 3 cannot recognise the arrival of the ACK message.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a transceiver circuit and method for ensuring normal packet transmission even if the distance between network nodes of a serial bus exceeds the 4.5-meter limit of the IEEE 1394 standard.

The stated object is obtained by setting the higher layer of a transceiver circuit to an idle state following the transmission of a packet for an interval corresponding to the turnaround time of a transmission medium connecting the transceiver circuit to a communicating transceiver circuit.

In general terms, the present invention provides a transceiver circuit of a network node for converting a signal received from a transmission medium to a decoded signal that can be recognised by a higher layer and transmitting packets received from the higher layer to the transmission medium, characterised by selector circuitry, and control circuitry for controlling the selector circuitry for supplying the decoded signal to the higher layer and supplying, instead of the decoded signal, an idle signal to the higher layer for a predefined time interval which starts at the end timing of a packet transmitted from the higher layer to the transmission medium, the idle signal indicating that the network node is in an idle state.

In specific terms, the present invention provides network node attached to a serial bus, comprising first circuitry for exchanging signals between the network node and a remote node attached to a distant end of the bus and determining therefrom a turnaround time between said nodes, and second circuitry for supplying a signal received from the serial bus to a higher layer and supplying, instead of said received signal, an idle signal to the higher layer

1 for an interval beginning with an end timing of a packet transmitted from the
2 higher layer to the bus until that interval corresponds to the turnaround time.
3 The first circuitry may increment a count value beginning with a start timing of
4 a child notify signal transmitted from the node to the bus and terminate the
5 increment of the count value at an end timing of a parent notify signal received
6 by the node from the bus to represent the turnaround time.

7 BRIEF DESCRIPTION OF THE DRAWINGS

8 The present invention will be described in further detail with reference
9 to the accompanying drawings, in which:

10 Fig. 1 is a sequence diagram of a typical Tree ID process between two
11 nodes;

12 Fig. 2 is a sequence diagram of a Normal process a state machine,
13 following a Tree ID process;

14 Fig. 3 is an illustration of various line states of twisted pairs when
15 contention occurs between two nodes;

16 Figs. 4A-4D are schematic illustrations of a three-node network when
17 contention occurs between packet transmissions;

18 Figs. 5A and 5B are sequence diagrams for describing details of
19 transmissions between two nodes of the three-node network of Figs. 4A-4D;

20 Fig. 6 is a block diagram of a network in which internodal distance
21 exceeds the 4.5-meter limit of the IEEE-1394 standard;

22 Fig. 7 is a block diagram showing details of a prior art long-distance
23 port used in the network of Fig. 6;

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1 Figs. 8A - 8C are schematic illustrations of a four-node network when a
2 contention occurs between packet transmissions over a section of the network
3 that exceeds the 4.5-meter limit;

4 Fig. 9 is a sequence diagram of signals exchanged between two nodes of
5 the network of Figs. 8A - 8C which are spaced a distance exceeding the 4.5-
6 meter limit for illustrating how a ghost Request signal is produced;

7 Fig. 10 is a block diagram of a transceiver circuit according to the
8 present invention;

9 Fig. 11 is a sequence diagram of a Tree ID process of the present
10 invention;

11 Fig. 12 is a sequence diagram of a Normal process of the present
12 invention; and

13 Fig. 13 is a flowchart for implementing the present invention in a
14 stored program.

15 DETAILED DESCRIPTION

16 Referring to Fig. 10, there is shown a long-distance IEEE-1394
17 transceiver circuit according to the present invention. This transceiver
18 circuit can be used as a long-distance (such as 8B/10) port of an IEEE-1394
19 network node. The transceiver circuit includes an 8B/10B encoder 21 for
20 encoding a signal from a higher layer to coded parallel data, which is
21 converted to a serial bit stream by a parallel-to-serial converter 22 and
22 forwarded onto a serial bus whose length to an adjacent node is longer than
23 4.5 meters. The parallel data from the higher layer is further supplied to a
24 start-of-Child-Notify detector 23 to produce a triggering signal for a time
25 counter 24 at the start timing of a Child Notify signal from the higher layer.

1 Signals from the serial bus are converted to parallel data in a serial-to-
2 parallel converter 25 and decoded by an 8B/10B decoder 26. The output of
3 decoder 26 is connected to an end-of-Parent-Notify detector 27 to produce a
4 stop-and-hold signal for the time counter 24 to stop its count operation and
5 hold the attained count value.

6 The time counter 24 of an IEEE-1394 node increments its count value
7 for an interval beginning with the start timing of a Child Notify signal
8 asserted by the local node to the end timing of a Parent Notify signal asserted
9 from a contending remote node. The output of time counter 24 represents the
10 turnaround time between the local node and the contending node. The
11 output of time counter 24 is obtained during a Tree ID process.

12 The output of decoder 26 is further supplied to a selector 29 to which
13 an idle state (pseudo-idle state) signal is also applied. Selector 29 receives a
14 control signal from a flip-flop 30 for selectively coupling the decoded signal
15 or the idle state signal to the higher layer.

16 An end-of-Data-End detector 31 is provided for detecting the end
17 timing of a Data-End signal transmitted from the local node to produce a
18 triggering signal for a time counter 32. Time counter 32 starts incrementing
19 its count in response to the detected end timing of the transmitted Data End
20 signal.

21 The count value of time counter 24 and the incrementing count value
22 of time counter 32 are compared by a comparator 33. Comparator 33
23 produces an output signal when the output of counter 32 equals the output of
24 counter 24.

25 Flip-flop 30 has a set input terminal (S) coupled to the output of end-

1 of-Data-End detector 31 and a reset input terminal (R) coupled to the output
2 of comparator 33. When the flip-flop 30 is set in response to the output of
3 end-of-Data-End detector 31, it controls the selector 29 to supply the idle state
4 signal to the higher layer. The application of the idle state signal to the higher
5 layer instead of the decoded bus signal prevents a deasserted Request signal
6 from the serial bus from entering the higher layer. Thus, "ghost" Request
7 signal no longer enters the state machine of the local node.

8 When the flip-flop 30 is reset by the comparator 33, it produces a signal
9 that causes the selector 29 to couple the decoded data to the higher layer,
10 instead of the idle state signal. Accordingly, immediately following the
11 detection of the end timing of a packet transmission, an idle state signal is
12 forcibly supplied to the higher layer as long as the operation of time counter
13 32 continues until its count value equals the internodal turnaround time.
14 Time counter 32 is reset to zero in response to the output of comparator 33 for
15 a subsequent packet transmission.

16 Time counters 24 and 32 are reset by a reset pulse initially produced at
17 the time the transceiver circuit is powered on. Thus, during a Tree ID process,
18 the flip-flop 30 is in a reset condition to supply a received bus signal to the
19 higher layer. During a subsequent Normal process, the flip-flop is switched
20 to set condition to supply an idle signal of duration corresponding to the
21 internodal turnaround time to the higher layer.

22 During the Tree ID process, one of a plurality of nodes of an IEEE-1394
23 serial bus is determined as a root node and the parent-child relationships of
24 the nodes are established. The operation of the transceiver circuit of Fig. 10
25 during the Tree ID process will be better understood by the following

1 description with reference to the sequence diagram of Fig. 11 by assuming
2 that the same four-node network as shown in Figs. 8A-8C is used and that the
3 transceiver circuit of the present invention is used in the long-distance port of
4 the nodes 3 and 4 of the four-node network.

5 Initially, the selectors 29 of nodes 3 and 4 are supplying decoded bus
6 signals from the output of their decoder 26 to their higher layer. Node 4 first
7 asserts a Parent Notify signal on the serial bus. On receiving the Parent
8 Notify signal, the node 3 asserts a Child Notify signal on the serial bus. At the
9 leading edge of the transmitted Child Notify signal, the start-of-Child-Notify
10 detector 23 of node 3 enables the counter 24 to start incrementing its count
11 value. Node 4, on receiving the Child Notify signal from node 3, deasserts the
12 Parent Notify and starts signalling an Idle state on the serial bus. In response
13 to the trailing edge of the received Parent Notify signal, the end-of-Parent-
14 Notify detector 27 of node 3 disables the counter 24 to stop incrementing its
15 count value. The count value "T" attained by the counter 24 of node 3 is thus
16 equal to the turnaround time between nodes 3 and 4. The counter 24 of node
17 4 remains at zero count value.

18 During a Normal process that follows, consider a situation similar to
19 that shown in Fig. 8A in which the node 4 asserts a Request signal when the
20 node 1 has already started transmitting packets. In this situation, the
21 operation of nodes 3 and 4 proceeds as illustrated in Fig. 12. During the time
22 node 3 is retransmitting the packets of node 2 to node 4, the node 3 is in state
23 RX (= Receive). At the end of the packet retransmission, the end-of-Data-End
24 detector 31 of node 3 drives the flip-flop 30 into set condition and enables the
25 counter 32 to start incrementing its count value. Selector 29 of node 3 is

1 therefore switched in response to the set condition of flip-flop 30 to supply
2 the idle state (pseudo-idle state) signal to the higher layer, instead of the
3 Request signal which the node 3 is receiving from the node 4. Thus, the state
4 machine of node 3 is in state A0 (= idle) for an interval "T" from the instant a
5 Data End message 50 has retransmitted to node 4 (Fig. 12) to the instant the
6 time counter 32 attains the same count value as that of time counter 24. On
7 receiving the retransmitted packet (i.e., DP, PKT, DE), the node 4 returns an
8 acknowledgment message (i.e., DP, ACK, DE) to the node 3. This
9 acknowledgment message arrives on the node 3 a period "T" after it has
10 repeated a Data End message 40 to the node 4. Thus, the arrival time of a
11 Data Prefix 41 of the acknowledgment message coincides with the instant at
12 which the state machine of node 3 changes from state A0 (= Idle) to state RX.

13 In this way, the node 3 prevents the propagation of a deasserted
14 Request signal of node 4 as a ghost signal to the root node 2 even though the
15 distance between nodes 3 and 4 exceeds the 4.5-meter limit. Therefore, the
16 node 3 can reliably receive an acknowledgment message from node 4,
17 signalling successful receipt of a packet from node 1.

18 The present invention can also be implemented by a programmed
19 routine stored in a storage medium as shown in Fig. 13. A Tree-ID process of
20 a node starts with initialization step 101 in which count variables C1 and C2
21 are set equal to zero. At step 102, the state machine of the node is set equal to
22 state RX to receive signals from the serial bus to the higher layer. Flow
23 proceeds to decision step 103 to determine whether the node has received the
24 starting point of a Child Notify signal from the higher layer. If the decision is
25 affirmative at step 103, the count value C1 is continuously incremented (step

1 104) . The routine proceeds to decision step 105 to determine whether a
2 Parent Notify signal has received. If so, the routine proceeds to step 106 to
3 stop incrementing the count value C1, terminating the Tree-ID process. The
4 routine enters the Normal process starting with step 107 in which the state
5 machine is set to state RX. If the node receives a Data End message from the
6 higher layer (step 108), the count value C2 is continuously incremented at
7 step 109 and the state machine is set to state A0 (= idle) at step 110. At
8 decision step 111, the count value C2 is compared with the count value C1
9 obtained by step 106. The state machine of the node is set to A0 (= idle) until
10 C2 becomes equal to C1, whereupon flow returns from step 111 to step 107 to
11 set the state machine to state RX to continue the Normal process.

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